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Use of genetic algorithms to improve the solid waste collection service in an urban area

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ABSTRACT

Increasing generation of Urban Solid Waste (USW) has become a significant issue in developing countries due to unprecedented population growth and high rates of urbanisation. This issue has exceeded current plans and programs of local governments to manage and dispose of USW. In this study, a Genetic Algorithm for Rule-set Production (GARP) integrated into a Geographic Information System (GIS) was used to find areas with socio-economic conditions that are representative of the generation of USW constituents in such areas. Socio-economic data of selected variables categorised by Basic Geostatistical Areas (BGAs) were taken from the 2000 National Population Census (NPC). USW and additional socio-economic data were collected during two survey campaigns in 1998 and 2004. Areas for sampling of USW were stratified into lower, middle and upper economic strata according to income. Data on USW constituents were analysed using descriptive statistics and Multivariate Analysis. ARC View 3.2 was used to convert the USW data and socio-economic variables to spatial data. Desk-top GARP software was run to generate a spatial model to identify areas with similar socio-economic conditions to those sampled. Results showed that socio-economic variables such as monthly income and education are positively correlated with waste constituents generated.

The GARP used in this study revealed BGAs with similar socio-economic conditions to those sampled, where a similar composition of waste constituents generated is expected. Our results may be useful to decrease USW management costs by improving the collection services.

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1. Introduction

In many developing countries, increasing generation of USW has exceeded action plans and collection programs of local governments, and has become an issue of concern to public health (Al-Khatib et al., 2007; Fauziah and Agamuthu, 2012). Additionally, USW is not characterised as frequently as required because most funding is allocated to collection service, which affects the recycling and collection processes. Furthermore, information regarding the management of USW is dispersed amongst different sources and generally lost with successive changes in government administration (Buenrostro et al., 2008). The selection of appropriate sites within the collection process is key to urban planning, as it may affect regional economic balances (Chang et al., 2008; Uyan, 2014). Therefore, modern streamlined collection systems are vital to ensure better management of USW, to reduce operational costs, and to improve the coverage and efficiency of collection services (Rada et al., 2013).

GIS can be used to make informed decisions relevant to USW management. Information from maps such as roads and settlements may be used to select the most appropriate sites to locate landfills (Delgado and Sendra, 2010; Rada et al., 2010; Demesouka et al., 2014). For instance, Vijay et al. (2005) input population density, demography, employment and communication

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routes into ArcGIS to forecast the generation of USW in India and improve the efficiency of collection routes by relocating USW containers. Nas et al. (2010) identified appropriate sites for landfills in Konya, Turkey, using ArcGIS with a multi-criteria evaluation analysis (MCEA). MCEA was used to weight the importance of urban settlements, roads, railways, agricultural land class, archaeological sites, wells, irrigational canals and land slope. The limitations of GIS were concluded to be the availability of relevant data.

The integration of USW data into GIS affords better designed and constructed models of urban areas to calculate variations in the generation of USW, which may result in reduced service costs (Karadimas and Loumos, 2008; Rada et al., 2013). Higgs (2006) combined GIS techniques with MCEA to accelerate decision making by including public opinion in the selection of programs to manage USW (De Feo and De Gisi, 2010; Castagna et al., 2013). By contrast, Chang et al. (2008) integrated environmental, bio-physical, ecological and socio-economic variables into ArcGIS to establish a spatial decision support system to select optimal sites to dispose of USW. A fuzzy multi-criteria algorithm using information on environmental impact, public transportation, aesthetic deterioration, and economic and public opinion, was run to select a landfill site.

GAs are widely used to automatically generate rules according to Fuzzy Rule Based Systems (FRBS) (Mohatar and Barranquero, 2007). Stockwell and Peters (1999) established that GAs represent a stochastic strategy to search in a space of potential solutions for a problem, such as modelling the laws of evolution with hereditary and environmental adaptations. The GARP has been used to model the ecological niche of a species, representing environmental conditions that are suitable to maintain their population.

Vioti et al. (2003) introduced a GA to solve the so-called "Travelling Salesman's Problem" (TSP), which is a typical approach to optimise waste collection routes. GAs are an alternative to traditional heuristic algorithms used to resolve the TSP, which lack precision and have long execution times. Vioti et al. (2003) referred to the projected algorithm as the Minimum Length Route (MLR), which requires several input parameters: number of nodes, distance between nodes, time required to empty the first waste container and to empty all the other containers, number and starting time of each time interval, costs of fuel and labor in each time interval, and name of street. The MLR algorithm was able to find faster solutions than the exact algorithm, and provided an improvement of 21% when compared with the heuristic algorithm. It was also applied to find the optimum collection route in a bourhood of Rome, Italy, and provided a 2% improvement compared with traditional algorithms.

Multi-Criteria Analyses (MCA) are required to make informed decisions due to the high number of variables and complexity of the management of USW. Karadimas et al. (2007) implemented GAs to simulate scenarios to optimise USW collection routes in Athens, Greece. They focused on optimising the collection and transportation of USW in containers by using six parameters to find possible solutions: iterations, population, children per generation, mutation policy and probability, and diversity threshold. It was concluded that GAs afforded a significant reduction of 9.62% of the waste collection route distance by comparison with the empirical method currently used by the municipality of Athens.

When conducting studies of USW generation, due to economical, logistic and operative constraints, the number of samples is typically the minimum statistically significant required. The use of GARP allows BGAs to be selected with socio-economic conditions within urban areas similar to those where analyses of USW generation are performed. It also allows the distribution of USW to be mapped within the urban areas. In this study, a GARP was used to find areas with socio-economic conditions that are representative of the generation of USW constituents in such areas.

2. Materials and methods

2.1. Study site and sampling campaigns

This study was carried out in Morelia, the capital city of the Michoacán state in western Mexico (Fig. 1). Morelia lies at an altitude of 1950 m above sea level, and covers an area of 1336 km^2. The climate is mild with an annual average rainfall of 770 mm and an annual average temperature between 14 and 18 °C. The population of the city is about 729,279 inhabitants (INEGI, 2010).

At Morelia, the collection, treatment and disposal of USW are co-ordinated by the municipal authority. The collection service is divided into municipal and private collection routes, which operate from Monday to Saturday and the whole week, respectively. USW is collected in plastic containers and plastic bags that are left outside dwellings, and in some neighbourhoods, at other designated sites, such as street corners according to established timetables. USW is commonly not separated, and only in few areas of the city are two fractions distinguished: (i) dry fraction (paper, cardboard, steel and plastic), and (ii) wet fraction (food and garden waste).

Two sampling campaigns were carried out in 1998 and 2004 to characterise the generation of USW in 229 and 269 dwellings, respectively. In each campaign, only dwellings with one family were found. Socio-economic data were obtained by conducting surveys. The sampled dwellings were chosen according to monthly income categorised into three socio-economic strata defined by INEGI (1990):

(i) Lower stratum: Up to 1 minimum wage monthly (Approx. $90.00 and $115.00 USD in 1998 and 2004, respectively).
(ii) Middle stratum: 1 to 2 minimum wages monthly (Approx. $182.00 and $230.00 USD in 1998 and 2004, respectively).
(iii) Upper stratum: 2 to 5 minimum wages monthly (Approx. $450.00 and $575.00 USD in 1998 and 2004, respectively).

Non-separated samples of USW generated at dwellings during the previous day were taken for further analysis in labelled plastic bags of size 60 × 90 cm. Sampling was carried out during 7 continuous days (one-week) according to the Official Mexican Standard (NMX-AA-061-1985; SECOFI, 1985). The collected plastic bags were weighed before separating the samples into individually weighed waste constituents (SECOFI, 1985). 65 different waste constituents were identified during both sampling campaigns (Table 1).

2.2. GARP description

GARP is an expert-system, machine-learning approach to predictive modelling (Stockwell and Noble, 1992; Stockwell and Peters, 1999). It uses an iterative process of rule selection, evaluation, testing, and incorporation or rejection. A method is chosen from a set of possibilities (e.g. logistic regression and bio-climatic rules), applied to training data, and a rule (which take the form of IF/THEN statements) is developed or evolved. Rules may evolve by several means that mimic DNA evolution: point mutations, deletions, crossing over, etc. Change in predictive accuracy from successive iterations is used to evaluate whether a certain rule should be incorporated into the model, and the algorithm either converges or runs 2560 iterations. When this process ceases, the model is projected back onto the landscape to predict geographical distributions in the form of a raster data grid, in which each square cell is designated as present or absent. Two types of data input are required to develop the spatial distribution: (i) location data points, which are the centroids of the study areas (BGAs), and (ii)

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